ESTIMATING THE COSTS OF RECOVERING FOREST RESIDUE IN THE NORTHERN ROCKY MOUNTAINS

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INTRODUCTION

The cost model described on the following pages provides cost estimates for collecting and transporting forest residue in the northern Rocky Mountains. The model builds on one developed by Withycombe in 1978 (Withycombe 1982).

Green sawtimber has long been the primary forest product in the northern Rocky Mountains. Although historically forest residue was considered a waste product, some of this wood fiber has always been used by the forest products industry. For example, the pulp and paper industry in the northern Rocky Mountains utilized dead timber when lumber and plywood production was down and the primary source of raw material, mill residue, was in short supply. In addition, the last fifteen years have seen a large increase in the number of house log manufacturers, many of whom depend entirely on dead timber. Numerous sawmills and cedar products manufacturers also depend on dead timber for some of their raw material needs.

As users of wood fiber began using raw material other than green sawtimber, they could choose from a number of sources. Most are included in the following major categories:

1. Nonsawtimber material on sites scheduled for logging that can be harvested in conjunction with conventional sawtimber harvesting operations;

2. Residual material from past years' logging operations;

3. Dead and cull green material on sites not scheduled for sawtimber harvesting operations;

4. Material cut in timber stand improvement practices such as thinning or stand conversion operations.

Material which can be harvested in conjunction with conventional sawtimber harvesting operations appears to offer the greatest immediate potential and has received the most attention from large volume users. It includes cull trees and logs, low value portions of sawtimber trees (tops, limbs, etc.) and small stems not part of sawtimber growing stock.

The cost model was developed to deal primarily with recovery of this component of the forest residue resource. It should also be useful in making estimates of the costs of recovering the other components listed on page one. However, the following information should be kept in mind when applying the model to recovery of any kind of forest residue.

First, the cost model includes only costs of the major activities undertaken on the logging site at the time of harvesting. It does not, therefore, include all of the potential costs which can be incurred in recovering forest residue. Specifically, the model consists of individual tables for estimating the cost of the following harvesting activities: hand felling, mechanical felling, ground skidding, cable yarding, in-woods chipping, log loading, and hauling. Not included are other costs such as allowances for administration and clerical workers, stumpage costs, landing or road construction costs. Also not included are implicit costs such as opportunity costs. These other costs are very specific to a given harvesting opportunity and firm. They do occur frequently and should be considered when appropriate.

A further caution: all of the activities do not represent costs which are relevant to the recovery of all types of wood fiber. For example, it would generally not be correct to assign a felling cost to the tops and limbs of sawtimber trees which are to be whole tree logged. Presumably, the tree will be felled whether or not the tops and limbs are to be recovered. If the same felling method is used regardless of whether tops and limbs are recovered, then no additional felling costs are incurred by the firm and none should be assigned to tops and limbs. It is the user's responsibility to identify those activities which would represent increased or incremental costs of operating on the site. See Appendix A for a more detailed discussion of cost allocation procedures.

Since the cost model was developed to deal primarily with the activity of recovering additional wood fiber in conjunction with a sawtimber logging operation, it was assumed that the volumes per acre harvested would be sufficient to allow a high level of equipment utilization. Therefore, all costs are expressed as variable costs in the cost tables. That is, the tables provide cost per unit output (in cunits) of performing various harvest activities. All equipment costs were treated as variable costs on the assumption that the forest residue would be harvested under a situation in which the logging equipment would be fully utilized and that new equipment would be available immediately at the same cost as existing equipment. Logging equipment costs, therefore, would vary directly with output.

If the model is to be used to estimate the cost of recovering material in situations where volumes per acre are relatively low (as might occur in relogging or salvage operations), the costs must be adjusted upward to account for lower equipment utilization.

A further discussion of the impact of operating equipment at low utilization levels is provided in Appendix B.

Of course, the reverse situation could also occur. A firm may presently be underutilizing its equipment. By recovering additional wood fiber, the firm could move closer to full utilization and have lower recovery costs for the additional material than those indicated in the tables. This is because some machine costs do not vary with output and are incurred even when the machinery is not operating. If the firm's logging equipment was under-utilized and the wood fiber could be recovered without additional equipment,

then costs not affected by volume harvested should not be charged to additional material recovered. Fixed equipment costs would include such items as loss in value of equipment due to the passage of time, interest expense, and insurance costs. Under this condition, skidding or yarding costs and haul costs would be somewhat lower than the costs shown in the tables. The degree of cost reduction would depend on the level of underutilization and the size of fixed costs.

A final caution: the tables are developed from average costs covering a broad range of operating conditions and are designed to make cost estimates for a large number of logging opportunities.

Data Sources

The cost tables are developed from 1) case studies of logging equipment or systems published in trade journals or as monographs, and 2) timber appraisal data developed by the U.S.D.A. Forest Service Region 1. Studies were selected to represent the conditions commonly encountered in the northern Rocky Mountains. All literature citations and additional reference material are provided in Appendix C.

For three activities -- hand felling, yarding with large cable systems, and inplant chipping -- little additional published information on cost has become available since Withycombe's analysis in 1978. The implicit price deflator for personal consumption expenditures from the U.S. Department of Commerce was used to update Withycombe's figures to 1982 dollars. New additions to the model include cost estimates for "small" mechanical fellers, rubber-tired grapple skidders, crawler tractors skidding with chokers, and yarding with small skyline systems. For the remaining activities -- "large" mechanical fellers, rubber-tired skidding with chokers, in-woods chipping, log loading, and hauling -- Withycombe's estimates were updated with new information.

USE OF THE COST MODEL

The Systems Approach to Harvesting Nonsawtimber Wood Fiber

The least expensive way to harvest any kind of timber is through a systems approach. The equipment and methods used at each phase in the harvesting process must be matched to the material to be harvested and the physical characteristics of the site. Constraints are often imposed by other phases of the operation. For example, if the material was bunched when felled, it would be less expensive to skid small timber with rubber-tired skidders with grapples than with rubber-tired skidders with chokers.

However, if the use of mechanical fellers were precluded by such things as soil type, bunching would not be possible. The use of chokers in skidding would then probably be cheaper than the use of a grapple skidder.

When choosing a system, the most important consideration is the final unit cost, not the cost of a single piece of equipment. Harvesting activities should operate together as an integrated system. The authors have tried to identify situations requiring one type of equipment or technique over another. This should allow the reader to estimate the cost of residue based on a systems approach to its removal.

IMPORTANT: To use the cost tables accurately it is imperative that the user also read Appendix B which describes the construction, use, and limitations of the individual cost tables and the models application to whole tree recovery systems.

Felling Costs (Tables 1 and 2, page 13)

Choosing whether to fell by hand or mechanically depends on slope, cutting method, terrain, stand density, and diameter distribution. Mechanical felling is less expensive than hand felling given proper diameter distribution, gentle terrain with slopes under 30 percent, and sufficient volumes per acre for the machines to operate at relatively high levels.[1] The cost savings occur because mechanical felling greatly reduces skidding costs by allowing for the grapple skidding or cable yarding of bunched material.

The question of when to mechanically fell and bunch, and what machine to use, cannot be answered with a set rule. Generally speaking, feller bunchers should be considered in stands where more than 90 percent of the volume is in timber less than 20 inches in diameter at the stump.

There are two types of mechanical fellers currently in operation: 1) the small models limited to clipping trees up to 13-inch diameters and generally limited to slopes under 15 percent, and 2) the larger models capable of clipping trees up to 20-inch diameters. These larger models are generally limited to slopes under 30 percent. Costs of both types of machines are provided in table 2; hand felling costs are provided in table 1.

In general, on stands fully stocked with slopes of less than 30 percent and timber of similar size (under 20 inches in diameter), mechanical felling is preferred over hand felling.

The authors feel that there will be sufficient volumes to run the machine at capacity when clearcutting or using seed tree cutting methods as regeneration systems in the northern Rocky Mountains. Therefore, assuming that the slope and timber size constraints are met, mechanical felling is appropriate for these sites.

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[1] Equipment such as the TIMBCO 2518 Hydro-buncher which can operate on steeper slopes is becoming available. Sufficient production data are not yet available to make accurate estimates of felling costs.

Thinning opportunities probably would be on sites with sufficient stems and volumes per acre to make mechanical felling preferable to hand felling if removal of the cut trees was desired.

Thinning operations can also be constrained by a need to protect the residual stand. However, in situations where wide spacing of leave trees was prescribed, or in stand conversion operations, mechanical felling followed by grapple skidding would generally be the most efficient way to recover cut trees.

Ground Skidding (tables 3, 4, and 5, page 14) or Cable Yarding (table 6, page 15).

Slope is the major determinant for choosing between ground skidding and cable yarding. Other significant considerations are environmental constraints and the road network of an area. Ground skidding machines are cheaper than large cable systems and are much easier to operate. The authors suggest ground skidding for slopes less than 35-40 percent.[2] On slopes greater than that, cable systems would be appropriate.

Low ground pressure tracked skidders have been permitted on steeper slopes on public lands. Only very limited data were available on these machines, but they are much more expensive to operate than conventional ground skidders.

Ground skidding can be accomplished with two types of machines: rubber-tired skidders or crawler tractors. Rubber-tired skidders are speedy and more maneuverable. Crawler tractors, on the other hand, are more versatile. They operate on steeper slopes, operate better under adverse weather conditions, and can be used for excavation and helping other equipment (table 5).

Because of this versatility many loggers have crawler tractors. Choosing between rubber-tired and tracked skidders therefore often depends on the equipment the logger has available and this in turn effects which table should be used. If information on equipment is not available, the assumption over a large number of sites that half the skidding will be with rubber-tired and half with tracked machines should have very little effect on the error of the estimated skidding cost.

Skidding with chokers is appropriate for situations where hand felling is initially used (table 3). Where mechanical fellers were used, rubber-tired grapple skidders are generally the most economical alternative when the slope is less than 35 percent (table 4).

The cost model offers two cable yarding alternatives: large cable systems and small skyline systems (table 6). Large cable systems are expensive, powerful, and work efficiently only with large timber and

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[2] On private lands tracked skidders are used on slopes above 35 percent. Costs of skidding on steeper slopes are certainly higher, however, making it less likely that large volumes of lower value nonsawtimber material could be recovered from steep slopes using tracked vehicles.

perhaps prebunched small timber. Many small skyline systems, fairly new to the northern Rocky Mountains, have been developed to recover small material.

The U.S.D.A. Forest Service (1983) has developed guidelines to use when considering a small skyline system. The average diameter of the timber to be harvested should be less than 12 inches (30 cubic foot piece) with no more than 10 percent of the volume coming from timber with diameters between 15-20 inches (40-80 cubic feet per piece). Yarding distance is generally limited to less than 1,000 feet. For stands with significantly different characteristics than these, large cable yarders are a necessity.

Loading and Transportation (tables 7, 8, and 9, page 16).

The final phase of the logging operation is transporting the residue from the landing to the millyard. The model provides two choices for transporting forest residue, in-woods chipping and hauling (table 8) or loading on to log trucks, hauling, and then chipping at the millyard (tables 7 and 9).

In-woods chipping requires a continuous supply of material to the chipper and large flat landings (about 75 feet by 150 feet) that are capable of holding a chip van, mobile chipper, and a log deck. In addition, the road network must be able to support a chip van.

For areas meeting these requirements, in-woods chipping is generally the cheapest alternative for recovering wood fiber from small stems. This is due primarily to the reduced log truck load size needed for hauling small stems (certainly under 6" d.b.h. and smaller). It is usually cheaper to chip larger material at the mill site since it requires a large stationary chipper which is better utilized at a central location. There may also be some product gain from sorting according to log quality at the mill.

In-woods chipping can be a relatively inexpensive method for moving wood fiber from the landing to the processing point given proper conditions. However, the costs of in-woods chipping are subject to a great deal of variation and can increase drastically if machinery is not properly utilized.

DATA REQUIREMENTS FOR USE OF THE COST MODEL

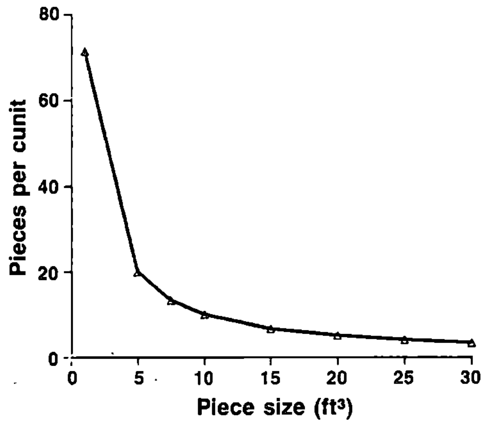
Certain data are required to use the cost tables accurately. Information such as piece size distribution, diameter distribution, average skidding or yarding distances, and haul distance are necessary to use all the cost tables.

The piece sizes in tables 3 through 11 (pages 14 - 17) are expressed in cubic feet, while most data will be reported in terms of diameter and length. Table 12, page 18, converts length and large end diameter (d.b.h. for full trees). to approximate cubic foot volume. The volumes shown include bark, an average of about 15 percent of the total volume for the typical Rocky Mountain species.

Piece Size Distribution

Harvesting forest residue requires handling small timber, therefore more pieces are handled per unit volume. Figure 1 illustrates this relationship and shows the number of pieces needed to produce a cunit (100 ft^3) of wood fiber by piece size.

Figure 1
Pieces per Cunit as a Function of Piece Size



The costs of felling, delimbing, ground skidding, cable yarding, and log loading are heavily influenced by piece size (or d.b.h.). As figures 2, 3, 4, and 5 illustrate, productivity drops sharply when average piece size drops below 10 cubic feet. Note the relationship between cost and piece size for the following activities: felling, ground skidding, cable yarding and log loading. The relationship between cost and piece size is nonlinear in all cases.

When dealing with a wide range of piece sizes, it is then essential to develop several size categories for the material being harvested to ensure reasonable cost estimates. This is illustrated by the following example:

Residue percent	Piece size ft^3	Cost to rubber-tire skid 300 ft (table 3) \$/cunit
30	2	62.5
50	10	12.5
20	50	8.3
Weighted Average	15.6	26.7

Figure 2
Cost of Hand and Mechanical Felling

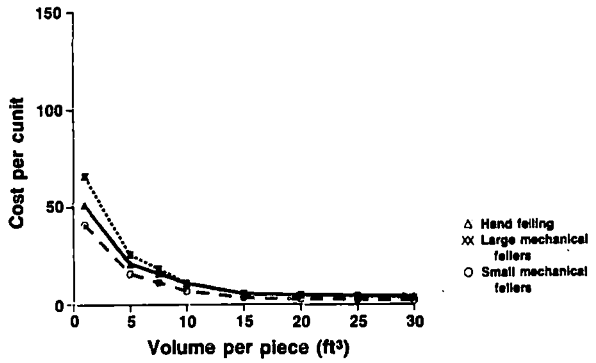


Figure 3
Cost of Ground Skidding a One-way Distance of 500 Feet

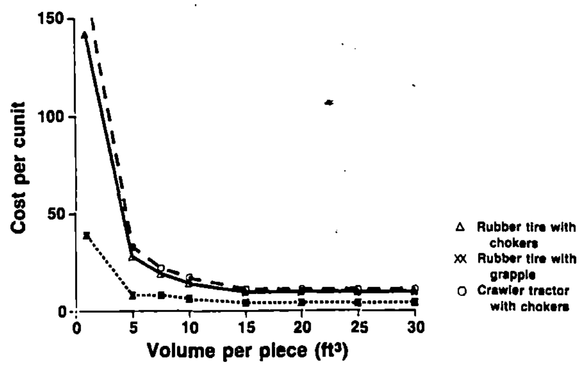


Figure 4
Cost of Cable Yarding

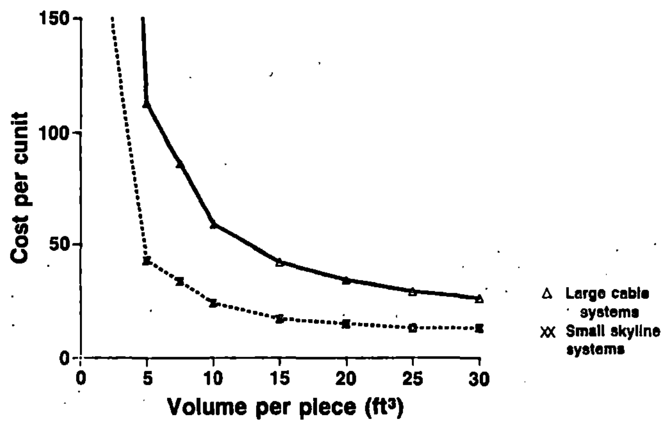
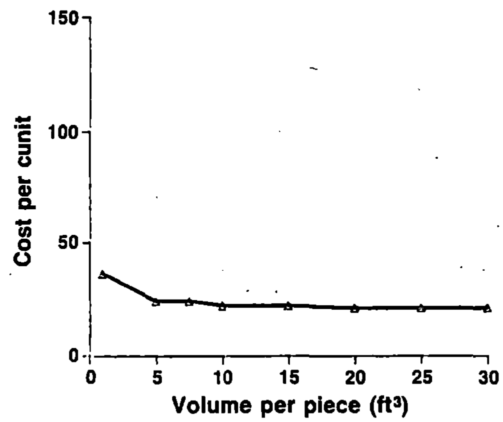


Figure 5
Cost of Loading and Hauling 50 Miles



For the piece size distribution described in the above example, the estimated weighted average cost per cunit is $26.7. However, if the piece sizes are averaged first using the same weights, average piece size is 15.6 ft^3. This, in turn, will yield an average cost of $8.3 per cunit, quite different from the cost obtained from the weighting scheme illustrated above. The authors suggest a user be especially careful when combining piece size categories for material under 10 ft^3 in size.

Diameter Distribution

The cost tables for both hand felling (table 1) and mechanical felling (table 2) require the diameter at breast height (d.b.h.). Since piece size is highly correlated to diameter, costs rise sharply at small diameters (figure 2). If the diameter distribution of the site being harvested is not homogenous, especially for the smaller sizes, more accurate felling cost estimates can be obtained by dividing the stand into a few separate diameter categories and developing a weighted average cost as described above.

Haul Distance

The cost tables for log loading and hauling (table 7) and in-woods chipping and hauling (table 8) require the one-way haul distance between the logging site and end user in addition to the piece size of the material. The tables assume the material would be hauled on dirt and gravel roads as well as on highways. The assumptions on road conditions are described in Appendix B. If local conditions vary greatly from the assumptions, the user can modify these estimates by referring to the description of table 7, in Appendix B.

Skidding or Yarding Distance

Skidding distance is a major factor in determining the cost of ground skidding. The relationship between cost and distance is linear, so one can use the average one-way skidding distance for an area or site.

The yarding distance also affects the cost of cable yarding, but to a much lesser degree. Because the cost differences are rather small they have been omitted from table 6. However, the costs in table 6 apply to yarding distances of less than 1,000 feet. For distances of 1,000 to 2,000 feet, the costs of large cable systems shown in table 6 should be increased by 20 percent. The table should not be used for distances over 2,000 feet.

EXAMPLES OF THE MODEL'S APPLICATION

Example 1: Recovery of forest residue in conjunction with sawtimber harvesting operations on flat ground.

For this example assume the residue has the following size distribution:

(a) 3 to 5-inch diameter standing trees, 20 percent of total volume.
(b) 5 to 7-inch diameter standing trees, 40 percent of total volume.
(c) 6 to 10-inch diameter standing dead or cull material, 20 percent of total volume.
(d) 11 to 20-inch diameter down dead or cull material that is 24 feet long, 20 percent of total volume.

The material is on flat ground with an average one-way skidding distance of 500 feet and a haul distance of 50 miles. The operation will use large feller bunchers, grapple skidding, and in-woods chipping without barking.

By using average diameters for each of the size classes, table 12 converts the piece size distribution to cubic feet. For the 3 to 5 and 5 to 7-inch diameter whole trees, it is assumed that during felling and skidding about 50 percent of the crown will be lost due to breakage. The following cubic foot volumes are then derived for the piece size distribution described above:

(a) 1.8 ft^3 per piece -- 20 percent of total volume.
(b) 4.4 ft^3 per piece -- 40 percent of total volume.
(c) 8.7 ft^3 per piece -- 20 percent of total volume.
(d) 27.8 ft^3 per piece -- 20 percent of total volume.

The appropriate cost tables are:

Table 2, mechanical felling, large feller buncher.
Table 4, rubber-tire grapple skidding.
Table 8, in-woods chipping and hauling.

The weighting scheme on page 7 is used to cost each size category.

Piece Size	Table 2	Table 4	Table 8	Total	Percent
	-------------	$/cunit	-------------		
(a) 1.8 ft^3	66.3	19.6	25.9	111.8	20
(b) 4.4 ft^3	25.8	9.8	25.9	61.5	40
(c) 8.7 ft^3	10.7	7.8	25.9	44.4	20
(d) 27.8 ft^3	----	3.9	25.9	29.8	20

The average cost weighted by percent is $61.8/cunit for unbarked chips delivered to the processing plant.

Example 2: High volume harvest of pole timber size lodgepole pine for fuelwood.

This example assumes that the site is on relatively flat ground with large landings available. The material is relatively uniform in size with an average d.b.h. of 6 inches. The average skid distance is 400 feet, and the haul distance is 40 miles. The material is to be chipped in-woods without barking.

The average volume per piece obtained from table 12 is between 3.6 ft^3 (without crown) and 5.2 ft^3 (with crown). It is assumed that during felling and skidding about 50 percent of the crown will be lost due to breakage. Consequently the recoverable piece size is 4.4 ft^3.

The tables used and the cost per cunit are:

	$/cunit
Table 2, mechanical felling, small feller buncher -- without limbing	15.9
Table 4, rubber-tired skidder (with grapple)	8.3
Table 8, in-woods chip and haul, not barked	23.0
Total cost/cunit	47.2

(Note: The tables are read to the closest value, without interpolation.)

Example 3: Recovery of forest residue in conjunction with sawtimber harvesting on steep ground in a clearcut.

For this example, assume that the residue has the following size distribution:

(a) 6 to 10-inch diameter, full trees, 20 percent of total.
(b) 10 to 14-inch diameter, 16 ft. long, 50 percent of total.
(c) 14 to 16-inch diameter, 24 ft. long, 30 percent of total.

All the material is on ground with slopes of 30 percent or greater within 500 feet of the logging road. The size class distribution of the original stand is rather homogenous, with an average diameter of less than 12 inches. The landings are too small to facilitate in-woods chipping. The one-way haul distance is 60 miles. Since the material is to be chipped for fuel, barking is not necessary.

For the 6 to 10-inch diameter whole trees it is assumed that during yarding and felling about 50 percent of the crown will be lost due to breakage. By using the average diameter for each size class, table 12 can convert the size class distribution to cubic feet.

(a) 10.1 ft^3 -- 20 percent of total volume.
(b) 10.6 ft^3 -- 50 percent of total volume.
(c) 23.0 ft^3 -- 30 percent of total volume.

The relevant cost tables are:

Table 6, cable yarding (small skyline systems -- without skidder).
Table 7, loading and hauling.
Table 9, in-plant chipping (chip only).
Each of the three piece size categories is costed separately.

Piece Size	Table 6	Table 7	Table 9	Total	Percent
	\$/cunit				
(a) 10.1 ft^3	23.7	24.6	8.6	56.9	20
(b) 10.6 ft^3	23.7	24.6	8.6	56.9	50
(c) 23.0 ft^3	13.3	23.3	8.6	45.2	30

Average cost weighted by percent is \$53.4/cunit.

RESIDUE COLLECTION COST TABLES
(In Constant 1982 Dollars)

Table 1 — Cost of Hand Felling

d.b.h.	Felling Only[1]	Limbing Only	Fell and Limb
Inches	-----------	$/Cunit	-----------
4	51.2	78.8	130.0
6	21.1	33.0	54.1
8	11.0	13.2	24.2
10	5.5	8.7	14.2
12	3.7	5.8	9.5
14	2.9	4.4	7.3
16	2.3	3.6	5.9
18	1.9	3.0	4.9
20	1.7	2.6	4.3
24	1.2	2.1	3.3
28	1.1	1.7	2.8

[1]Costs are based on recovery of bole volume only.

Table 2 — Cost of Mechanical Felling

		Large Feller Bunchers		Small Feller Bunchers
d.b.h.	Bole Volume Per Tree	Fell Only[1]	Fell and Limb	Fell Only[1]
Inches	Ft^3	-----------	$/Cunit	-----------
4	1.4	66.3	80.0	40.8
6	3.6	25.8	31.1	15.9
8	8.7	10.7	12.9	6.6
10	16.3	5.7	6.9	3.5
12	27.4	3.4	4.1	2.1
14	40.0	2.3	2.8	---
16	55.8	1.7	2.0	---
18	75.1	1.2	1.5	---
20	98.2	0.9	1.1	---

[1]Costs are based on recovery of bole volume only.

(In Constant 1982 Dollars)

Table 3 — Cost of Rubber-Tired Skidding (with chokers)

Volume per Piece	Volume per Load[1]	One-Way Skidding Distance (Feet) 50	100	150	200	300	400	500	600	800	1,000	2,000	3,000
Ft^3	Ft^3	$/Cunit											
0.5	5	208.3	216.8	225.3	233.2	250.0	266.6	283.6	299.6	333.4	367.0	533.4	701.8
1.0	10	104.2	108.4	112.7	116.6	125.0	133.3	141.8	149.8	166.7	183.5	266.7	350.9
1.5	15	69.4	72.3	75.1	77.7	83.3	88.9	94.6	100.0	111.1	122.3	177.8	233.9
2.0	20	52.1	54.2	56.3	58.3	62.5	66.7	70.9	74.9	83.3	91.7	133.3	175.4
3.0	30	34.7	36.1	37.6	38.9	41.7	44.4	47.3	49.9	55.5	61.7	88.9	117.0
4.0	40	26.0	27.1	28.2	29.1	31.2	33.3	35.5	37.5	41.7	45.9	66.7	87.7
5.0	50	20.8	21.7	22.5	23.3	25.0	26.7	28.4	30.0	33.3	36.7	53.3	70.2
7.5	75	13.9	14.5	15.0	15.6	16.7	17.8	18.9	20.0	22.2	24.5	35.6	46.8
10.0	100	10.4	10.8	11.3	11.7	12.5	13.3	14.2	15.0	16.7	18.3	26.7	35.1
15.0 and over	150+	6.9	7.2	7.5	7.8	8.3	8.9	9.5	10.0	11.1	12.2	17.8	23.4

[1]Volume per load assumes 10 pieces per load to a maximum load of 150 Ft^3.

Table 4 — Cost of Rubber-Tired Skidding (with grapple)

Volume per Piece	Volume per Load[1]	One-Way Skidding Distance (Feet) 50	100	150	200	300	400	500	600	800	1,000	2,000	3,000
Ft^3	Ft^3	$/Cunit											
0.5	7.5	27.8	33.3	38.9	44.4	55.5	66.7	78.4	88.9	111.1	133.3	242.4	355.5
1.0	15.0	13.9	16.7	19.5	22.2	27.8	33.3	39.2	44.4	55.6	66.7	121.2	177.8
1.5	22.5	9.3	11.1	13.0	14.8	18.5	22.2	26.1	29.6	37.0	44.4	80.8	118.5
2.0	30.0	6.9	8.3	9.7	11.1	13.9	16.7	19.6	22.2	27.8	33.3	60.6	88.9
3.0	45.0	4.6	5.6	6.5	7.4	9.3	11.1	13.1	14.8	18.5	22.2	40.4	59.3
4.0	60.0	3.5	4.2	4.9	5.6	6.9	8.3	9.8	11.1	13.9	16.7	30.3	44.4
5.0	75.0	2.8	3.3	3.9	4.4	5.6	6.7	7.8	8.9	11.1	13.3	24.2	35.6
7.5	75.0	2.8	3.3	3.9	4.4	5.6	6.7	7.8	8.9	11.1	13.3	24.2	35.6
10.0	100.0	2.1	2.5	2.9	3.3	4.2	5.0	5.9	6.7	8.3	10.0	18.2	26.7
15.0 and over	150+	1.4	1.7	1.9	2.2	2.8	3.3	3.9	4.4	5.6	6.7	12.1	17.8

[1]Volume per load assumes 15 pieces per load for pieces less than 5 Ft^3 and 10 pieces per load for pieces larger than 5 Ft^3.

Table 5 — Cost of Crawler Tractor Skidding (with chokers)

Volume per Piece	Volume per Load[1]	One-Way Skidding Distance (Feet) 50	100	150	200	300	400	500	600	800	1,000	2,000	3,000
Ft^3	Ft^3	$/Cunit											
0.5	5	251.9	260.8	269.4	279.6	297.2	314.2	333.4	351.0	385.8	423.0	600.0	776.4
1.0	10	125.9	130.4	134.7	139.8	148.6	157.1	166.7	175.5	192.9	211.5	300.0	388.2
1.5	15	84.0	86.9	89.8	93.2	99.1	104.8	111.1	117.0	128.6	141.0	200.0	258.8
2.0	20	63.0	65.2	67.3	69.9	74.3	78.6	83.3	87.8	96.5	105.8	150.0	194.1
3.0	30	41.9	43.5	45.0	46.6	49.5	52.4	55.5	58.5	64.3	70.5	100.0	129.4
4.0	40	31.5	32.6	33.7	34.9	37.2	39.3	41.7	43.9	48.2	52.9	75.0	97.1
5.0	50	25.2	26.0	27.0	28.0	29.8	31.4	33.4	35.2	38.6	42.4	60.0	77.6
7.5	75	16.8	17.4	18.0	18.6	19.8	21.0	22.2	23.4	25.7	28.2	40.0	51.8
10.0	100	12.6	13.0	13.5	14.0	14.9	15.7	16.7	17.6	19.3	21.2	30.0	38.8
15.0 and over	150+	8.4	8.7	9.0	9.3	9.9	10.5	11.1	11.7	12.9	14.1	20.0	25.9

[1]Volume per load assumes 10 pieces per load to a maximum load of 150 Ft^3.

(In Constant 1982 Dollars)

Table 6 — Cost of Cable Yarding

Average Piece Size	Large Cable Yarders[1]	Small Skyline Yarders: Without Skidders	Small Skyline Yarders: With Skidders
Ft^3	$/Cunit		
0.5	1,058.0	402.9	604.3
1.0	537.0	202.9	304.3
1.5	359.0	136.3	204.4
2.0	271.0	103.7	155.5
3.0	183.0	70.0	105.0
4.0	139.0	53.3	80.0
5.0	113.0	43.4	65.1
10.0	59.4	23.7	35.6
15.0	42.3	17.4	26.2
20.0	34.1	14.7	22.0
25.0	29.3	13.3	19.9
30.0	26.5	12.8	19.2
40.0	23.6	----	----
50.0	22.0	----	----
60.0	19.2	----	----
70.0	17.0	----	----
80.0	15.3	----	----
90.0	13.9	----	----
100.0	12.8	----	----

[1] For yarding of 1,000 feet to no more than 2,000 feet, increase the cost shown by 20 percent.

(In Constant 1982 Dollars)

Table 7 — Cost of Loading and Hauling

Average Volume per Piece	One-Way Haul Distance (Miles)									
	10	20	30	40	50	60	70	80	90	100
Ft^3	$/Cunit									
1.0	20.8	24.3	28.3	32.2	36.1	39.8	43.3	46.8	50.1	53.3
2.0	16.8	19.6	22.9	26.0	29.2	32.2	35.0	37.8	40.5	43.1
3.0	15.6	18.3	21.3	24.3	27.2	30.0	32.7	35.3	37.8	40.2
4.0	14.6	17.1	20.0	22.7	25.5	28.1	30.6	33.1	35.4	37.7
5.0	14.1	16.5	19.2	21.9	24.5	27.0	29.4	31.8	34.0	36.2
7.5	13.6	15.9	18.5	21.1	23.6	26.0	28.3	30.6	32.7	34.9
10.0	12.2	14.5	17.1	19.7	22.2	24.6	26.9	29.2	31.3	33.5
15.0	12.2	14.5	17.1	19.7	22.2	24.6	26.9	29.2	31.3	33.5
20.0	10.9	13.2	15.8	18.4	20.9	23.3	25.6	27.9	30.0	32.2
30.0	10.9	13.2	15.8	18.4	20.9	23.3	25.6	27.9	30.0	32.2
40.0	9.5	11.8	14.4	17.0	19.5	21.9	24.2	26.5	28.6	30.8
50.0	9.5	11.8	14.4	17.0	19.5	21.9	24.2	26.5	28.6	30.8
75.0	8.2	10.5	13.1	15.7	18.2	20.6	22.9	25.2	27.3	29.5
100.0	8.2	10.5	13.1	15.7	18.2	20.6	22.9	25.2	27.3	29.5

Table 8 — Cost of In-Woods Chipping[1] and Hauling

One-Way Haul Distance	Barked Chips[2]	Not Barked Chips[2]
Miles	$/Cunit	
10	16.5	14.7
20	18.7	16.9
30	22.0	20.2
40	24.8	23.0
50	27.7	25.9
60	30.3	28.5
70	32.9	31.1
80	35.4	33.6
90	37.8	36.0
100	40.2	38.4

[1]Chipping costs are: barked $10.4/cunit; not barked $8.6/cunit.

[2]If the residues are to be barked prior to chipping, table 1 or 2 (if used) must provide for limbing. If the residues are not barked, limbing is not required.

Table 9 — Cost of In-Plant Chipping

	$/Cunit
Chip only[1]	8.6
Handling costs[2]	8.6

[1]Chipping costs include chipper, labor, power, and limited yard handling.

[2]Handling costs include barking, bark and chip handling, and storage and screening of chips.

(In Constant 1982 Dollars)

Table 10 — Cost of Loading

Average Volume per Piece	Weight of Full Load	Cunits per Load	Loading Cost
Ft^3	1,000 Pounds		\$/Cunit
1.0	34	6.8	12.4
2.0	42	8.4	10.0
3.0	45	9.0	9.3
4.0	48	9.6	8.7
5.0	50	10.0	8.4
7.5	52	10.4	8.1
10.0	52	10.4	6.7
15.0	52	10.4	6.7
20.0	52	10.4	5.4
30.0	52	10.4	5.4
40.0	52	10.4	4.0
50.0	52	10.4	4.0
75.0	52	10.4	2.7
100.0	52	10.4	2.7

Table 11 — Cost of Hauling

	--- Assumed Values ----					
One-Way Distance	Dirt Road	Gravel Road	Paved Road	Roundtrip Time	Cost per Trip	\$/Cunit[1]
Miles	Miles	Miles	Miles	Minutes	Dollars	
10	2	2	6	86	56.8	5.5
20	2	4	12	119	81.0	7.8
30	3	6	21	157	108.2	10.4
40	4	8	28	194	134.8	13.0
50	5	10	35	231	161.4	15.5
60	5	12	43	265	186.2	17.9
70	5	14	51	298	210.4	20.2
80	5	15	60	330	233.9	22.5
90	5	15	70	360	256.2	24.6
100	5	15	80	390	278.5	26.8

[1]Based on 10.4 cunits per load.

Table 12 — Volumes of Selected Stems and Stem Segments in Typical Northern Rocky Mountain Stands; Cubic Feet, Including Bark

Large End Diameter or d.b.h.	Tree Segment Length (ft) 8	16	24	32	Total Volume (including top)	Total Volume (including top & crown)
Inches	Cubic Feet					
4	0.5	0.9	1.1	1.4	1.4	2.2
6	1.3	2.3	2.9	3.5	3.6	5.2
8	2.5	4.4	5.8	7.0	8.7	11.5
10	3.9	7.2	9.8	11.9	16.3	20.7
12	5.8	10.6	14.7	18.2	27.4	33.7
14	8.0	14.8	20.7	25.8	40.0	48.5
16	10.5	19.7	27.8	34.9	55.8	66.7
18	13.4	25.3	35.9	45.4	75.1	89.0
20	16.6	31.6	45.1	57.2	98.2	115.5
24	24.1	46.2	66.6	85.2	157.0	183.6
28	33.0	63.7	92.2	118.8	235.2	272.5
32	43.3	83.9	122.0	158.0	335.0	384.9

Notes: Volumes not listed may be calculated using Smalian's Rules. Table assumes taper of 1 inch per 8 feet.

$$V = .005454 \frac{(L\ (D^2_s + D^2_l)}{2}$$

L = Length in feet.
D_s = Small end diameter in inches.
D_l = Large end diameter in inches.

To obtain volume without bark, reduce the tabled values by 8 percent for lodgepole pine, or by 20 percent for other species.

APPENDIX A

COST ALLOCATION IN FOREST RESIDUE RECOVERY

Allocating the costs of timber harvest activities to various sawtimber and other products harvested simultaneously is complex. Sometimes all of the costs should be assigned to only one of the products, such as sawtimber, while in other cases the costs should be shared by several products such as sawtimber, pulpwood, or fuelwood.

This section discusses costs that can affect a decision to harvest wood fiber other than sawtimber. Alternative sources of wood fiber are often available, and choices between them should be made on the basis of their relative costs.

There are two types of costs: incremental costs and sunk costs. Incremental costs are those that will change depending on what action is taken, and should therefore be considered when making decisions between possible actions. Sunk costs are those that will not be affected by the decision, and so need not be considered. To a firm faced with a choice between two harvesting systems to harvest a stand of timber that was already purchased, the logging costs would be incremental; they will occur in the future and they will vary depending on the choice made. The stumpage cost paid for the timber has already been incurred and will not change regardless what choice is made. Therefore, it is a sunk cost. Simple categories cannot be used to identify incremental and sunk costs because they change with the situation.

Incremental costs can be either explicit or implicit. Explicit costs are those that are determined by a cash outlay and are usually easy to identify. Implicit costs do not involve cash, but affect the firm nonetheless. Examples are the opportunity cost of passing up other profitable logging operations to harvest low value forest residue, or the possible increase in sawtimber pirated by woodcutters because of the removal of dead timber.

Identification and Allocation of Costs

Estimating the costs of obtaining sawtimber or other outputs involves two steps. First is the identification of the relevant costs and their magnitudes and second is the allocation of the costs among the various outputs.

Only the incremental costs (inputs) should be considered when deciding whether to harvest additional wood fiber, but they may be either explicit costs or implicit costs. The incremental benefits (outputs) must also be identified, and may also be explicit or implicit. Explicit outputs are products such as sawtimber or pulpwood, and implicit outputs would include benefits such as reduced insect hazard or increased growth potential of the residual stand.

To determine the incremental costs and benefits of harvesting additional material such as forest residue from a given site, the following three questions must be answered:

(a) What activities will be undertaken regardless of whether the forest residue is harvested?
(b) What additional activities, and related costs, will be incurred to harvest the additional wood fiber?
(c) What are the intended outputs or benefits of the additional activities?

Of the many possible combinations of answers to these three questions, three general cases have been identified that relate to the harvest of forest residue material.

Case 1: Forest residue will be taken from a site on which the firm would be operating anyway, to harvest sawtimber or accomplish some land management activity such as thinning. The value of the forest residue would thus not be a factor in the decision of whether or not to operate at that site.

Case 2: Forest residue will be taken from a site where it is the only output, so that the costs and values of the wood fiber recovery activities are the sole determinant of whether or not to operate.

Case 3: Forest residue will be taken from a site where the value of the forest residue and other outputs were both factors in the decision to operate or not.

Cost Allocations Between Forest Residue and Other Outputs

Case 1: If a site is to be worked for outputs other than forest residue, then the only costs allocated to the forest residue should be the incremental costs of harvesting it. In this case, all costs incurred to obtain the primary output of sawtimber or a timber management objective should be assigned to the primary outputs. The wood fiber would be allocated only costs that are in addition to what is required for the primary output. The wood fiber becomes a "bonus" output in this case.

For example, if a stand of timber has been purchased with the intent to log it for sawtimber, then any costs such as road construction, equipment move in, and direct operating costs of logging sawtimber would be assigned to the sawtimber that is produced. Forest residue that is produced at the same time would be assigned only those costs incurred beyond the costs for the sawtimber. It is not necessary that the harvest of forest residue be actually separated from the sawtimber harvest.

The incremental cost of the forest residue is the difference between the total cost and the cost that would have been incurred to log the sawtimber.

This concept can be extended to land management objectives as well as sawtimber. If a stand is to be thinned to promote growth, then any forest residue recovered from the thinnings would to some extent be a bonus product. If the thinning prescription called for falling small material and leaving it where it fell, then any costs of yarding and transporting the material would clearly be an incremental cost that should be allocated to the forest residue. If a more expensive falling method, such as a large mechanical feller were used to facilitate the skidding, then the added cost of the feller-buncher would be allocated to forest residue, but the equivalent cost of chainsaw felling would be allocated to the thinning.

Case 2: A site that is harvested only for forest residue represents a straightforward costing analysis. All costs incurred to operate on the site, including fixed costs such as setup or road construction costs, or implicit costs such as the lost opportunity of operating elsewhere, should be assigned to the forest residue.

Case 3: The situation where the values of both the forest residue and other outputs were considered in the decision to operate on a site or not represents the most difficult cost allocation problem. Some costs are associated only with one output, and so can be assigned directly to it. For example, if a chipper were set up for the sole purpose of chipping the wood fiber, then all costs associated with the chipper would be allocated to the forest residue.

Some costs, however, cannot be assigned directly to any one output, and are referred to as joint costs. There are no "correct" ways to allocate joint costs to the various outputs. It must be done arbitrarily.

This especially becomes a problem if the firm has alternative sources of wood fiber. In order to choose between forest residue (given case 3) and, for example, mill residue on the basis of cost, it is necessary to be able to assign a cost to both components.

The amount of costs which may have to be allocated could in many cases be small. If, for example, the firm decides to operate on a site based on the value of sawtimber and large dead timber for pulpwood, then the joint costs might be limited to those of moving and setting up logging equipment. Truly joint costs would then represent only a small percentage of total logging costs and the arbitrary allocation of joint costs to sawtimber and forest residue products would probably have very little effect on the error of the cost estimate of recovering these products.

There are many cases, however, when a large portion of the harvest costs would be joint costs. If the joint costs for a particular stand are high then an arbitrary allocation of these costs to the products could greatly

increase the error involved in estimating the cost of forest residue. A determination of whether or not stands of this type should be used as a source of forest residue must involve a comparison of not only costs, but also revenues for various mixes of alternative wood fiber sources.

Dealing with Truly Joint Costs

It is highly unlikely that a firm would be able to undertake the kind of complex revenue/cost analysis necessary to choose among alternative sources of wood fiber with joint product cost outputs. This would require analyzing very large numbers of stands and treatments. Further, future values of land management treatments can be estimated only very grossly making a sophisticated optimum choice analysis almost meaningless.

Firms might much more easily identify treatments which have high positive values, thereby identifying these areas on which they can, for example, thin regardless of the value of the forest residue felled. The choice of sites on which the firm will operate to fulfill land management objectives and recover products, therefore, probably must be made in a rather gross manner. A reasonable approach might be to operate on:

(1) areas with high potential to return value for treatment as perhaps would be the case with thinning opportunities on very productive sites, or
(2) areas with relatively high value in the material to be harvested so that all or most of the cost of the operation could be recovered in product value immediately.

If a firm did this it would be undertaking operations which likely had a positive net value to the firm, but probably would not be maximizing theoretical net benefit to the firm.

Many cost items that at first appear to be joint costs can, with careful analysis, be allocated to one of the outputs. If the same ground skidding equipment is used to skid both sawlogs and forest residue, then the cost of the skidder would appear to be a joint cost. However, a careful analysis should reveal the proportion of the skidder's time spent on each output. Since the operating costs are directly proportional to the time spent, it would then be possible to allocate the cost of the skidder to the two outputs according to the time, without resorting to an arbitrary allocation. The cost of moving the skidder, however, would be a true joint cost, and would require an arbitrary allocation.

The Kind of Material Removed and Its Impact on Relevant Costs

The kinds of forest residue material harvested are very important in determining what costs are relevant in a given case. Forest residue generally will be in one of three categories in the northern Rocky Mountains: (1) large dead or cull green material, (2) small stems and (3) limbs, tops, needles, and cull portions of sawtimber trees.

The same activities and costs would not be relevant to each of the three categories of forest residue, even if the material were all recovered from the same site simultaneously.

The situations illustrated below correspond to case 1 or 2, where the forest residue is harvested with sawtimber as a "bonus" product, or where it is harvested as a sole product.

A. Large Dead or Cull Green Material.

Large snags or cull green trees that are harvested for wood fiber should be assigned the cost of limbing and bucking, skidding, loading, hauling, and unloading. Fellings costs are excluded since the material would be already down, or would be felled as a safety measure as part of the harvest of sawtimber. If the snags were harvested separately from sawtimber, a felling cost should be included, but only when the snags or cull trees are taken as a part of a wood fiber only harvest. On National Forest lands, snags are frequently left standing for wildlife habitat, and are not available for removal.

B. Small Stems.

The relevant costs would include all harvesting costs except for limbing and bucking. Since the limbs, needles, and tops are as desirable for fuel as the bole, it is assumed that the small stems will be whole tree logged and hauled, and then hogged or chipped whole.

C. Low-Value Portions of Sawtimber Trees.

Significant amounts of wood fiber material can be recovered from the tops and limbs of small to medium-size sawtimber that is whole tree logged. It is again assumed that the potential value of the wood fiber would not be a factor in determining whether or not to operate, so that the wood fiber is a "bonus" product. The only relevant costs of the fiber would be the added costs of operation required to recover it. When the trees are skidded whole, and then limbed and bucked at a central location, there appears to be essentially no added cost. There may be a slight increase in skidding cost, and in limbing and bucking cost, but sufficient information is not available to estimate the difference with any assurance. It is assumed that the costs to fell, limb, buck, and skid whole trees are the same as for logs, and that there is therefore no cost for these activities allocated to the wood fiber produced.

The cost of loading, hauling, and unloading whole trees is greater than it is for sawlogs, so a portion of these costs must be allocated to the wood fiber. Loading and unloading both take longer with whole trees because of the added bulk and the interlocking of limbs. The tops and limbs displace sawlogs on the truck,

so that a truck loaded to its weight limit would contain less sawlog material than if there were no tops. An additional cost may also be incurred with small stems because the bulk density of the load might not permit a full weight load. It is assumed that the costs of loading and hauling will be increased in proportion to the volume of wood fiber to sawlogs.

Case 3 considers the value of forest residue in the decision to operate on a site and represents the most difficult allocation problem. The choices faced by a firm are varied and it is difficult to detail specific guidelines for cost allocation. What is important is that the firm must always examine its decision process and determine what additional costs it will undertake to recover the forest residue. Additional costs will be dependent on the situation under which the material is harvested and the kind of material harvested.

APPENDIX B

CONSTRUCTION, USE, AND LIMITATIONS OF THE COST TABLES

As stated earlier, this cost model builds on one developed by Withycombe in 1978 (Withycombe 1982). For two activities -- hand felling and yarding with large cable systems -- little additional information on cost has become available since then. In these cases the implicit price deflator for personal consumption expenditures from the U.S. Department of Commerce was used to update Withycombe's figures to 1982 dollars. For the other activities, considerable additional information was used to construct the cost tables. The data sources are referenced below and listed in Appendix C on pages C1-C5.

This section offers a more detailed description of how the cost tables were developed, further explanation on how the tables should be used, and some cautions to be aware of when using the tables.

Machine costs. Machine costs for the harvest activities described below were derived from case studies and local equipment dealers and include only costs for new equipment. The following assumptions were used to set the hourly equipment costs: the economic life of the equipment would be 5 years; salvage value would be 20 percent using straight line depreciation; interest rates were assumed to be 15 percent; yearly taxes and insurance combined were estimated at 4.5 percent of the depreciable value; and scheduled machine hours were assumed to be 1,600 hours per year. Operating costs which include wages and benefits for the operator, machine repair and maintenance, and costs of fuel lubricants and tires were obtained from individual case studies.

The required capital investment for new equipment can be reduced substantially by purchasing used equipment. However, buying used equipment will not necessarily reduce the cost per cunit of harvesting forest residue. Used equipment will have about the same dollar level of annual depreciation as new, because of the reduced economic life, and the savings in interest expense will probably be offset by higher maintenance. Therefore, the authors feel that used equipment would lower the capital requirements and risk involved, but probably would not lower the cost per cunit of harvesting.

Table 1: Cost of Hand Felling. The costs of hand felling were estimated by Withycombe (1982). The sources agree for diameters between 8 to 10 inches and the estimates should be fairly accurate for this size. Beyond this range, however, large variations occur, especially for small sizes. For example, the cost range in the supporting literature for 4-inch d.b.h. material differed from the average costs in the table by as much as 50 percent. The costs shown for limbing and bucking include one bucking cut to overall length.

Table 2: Cost of Mechanical Felling. Since the study by Withycombe (1982), the Forest Engineering Research Institute of Canada (FERIC) and U.S.D.A. Forest Service have conducted and published extensive studies of mechanical felling in the northern Rocky Mountains and interior British Columbia. The costs developed in table 2 are from the following sources: Folkema (1979), Goetz (1982), Host and Lowery (1983), Mandzak et al. (1981), McMorland (1980, 1982), Powell and St. Jean (1979), Spahr (1981), and Withycombe (1982).

The cost and productivity associated with mechanically felling timber varies according to stand density, stand size class distribution, terrain, and slope, to name a few of the important variables. The mechanical feller studied produced from 50 to 125 trees per productive machine hour (PMH).[1] The average production level was calculated at 87 trees per PMH. Production of mechanical fellers while limbing was estimated at 72 trees per PMH. There were two distinct classes of mechanical fellers studied: 1) small models limited to clipping trees up to 13-inch diameters and 2) larger models capable of clipping trees up to 20-inch diameters. The production figures do not correlate to machine size as long as the machines are operating in timber of the appropriate size. The average should, therefore, work well for the large or small machines.

Utilization levels were estimated at about 80 percent for both machines.[2] Therefore, table 2 was developed assuming an hourly production of 70 trees without limbing and 58 trees per hour with limbing. Variations in production costs surfaced here also, and individual cost estimates deviated from those in table 2 by as much as 70 percent.

Hourly costs used to develop table 2 include machine and operator costs. Machine costs for the larger mechanical fellers (e.g. Drott 40LC, TIMBCO 2518 Hydro-Buncher) were estimated at $50 per hour. Costs for the smaller models (e.g., Melroe Model 1075, Morbell Mark IV Feller-Buncher) were estimated at $25 per hour. Operator costs were estimated at $15 per hour.

Tables 3, 4, and 5: Cost of Ground Skidding. Tables were developed for the three alternative systems of ground skidding commonly available in the northern Rocky Mountains. The tables are based on production estimates from: Chase (1979), FERIC (1979), Gardner (1979, 1982), Mandzak et al. (1981), McIntosh and Johnson (1974), McMorland (1980), Powell (1978), Schillings (1969), and Withycombe (1982). The studies were combined using average values for all variables except distance.

Table 3 shows the production costs for rubber-tired skidders using chokers. The production equation used to develop the table is T = 12.0

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[1]Productive machine hours include only the amount of time working; it does not include nonmechanical or mechanical downtime.
[2]Utilization rates are the ratio of productive machine hours to scheduled machine hours.

+ 0.01 (D), where T equals turn time in minutes and D is one-way skidding distance in feet. The assumptions used in developing the table were:

- Machine utilization would be 80 percent.
- Machine costs were $25 per hour. This is equivalent to what would be expected with a 90 h.p. machine. Operator costs were assumed to be $15 per hour.
- The skidder would turn 10 logs and the load volume would not exceed 150 ft^3.

Departures from skidding 10 logs per turn can greatly affect unit cost.

To illustrate, skidding consists of four operations: moving the machine from the landing to the logs, attaching the logs to the skidder by chokers or grapple, moving the logs to the landing, and unattaching and decking the logs. Assuming that log weight does not exceed the capacity of the machine, the time and cost required to move back and forth from the landing to the logs is virtually unaffected by the number of pieces per turn. Given a turn of 5 versus 10 logs of the same size, the production rate of these two components would be almost halved, the cost would be nearly doubled, and total skidding costs would greatly increase.

Unfortunately, the data were not detailed enough to develop a precise cost relationship among the components of the skidding process. The user is warned to be aware that if low volumes per acre are encountered costs can increase greatly.

Table 4 illustrates the costs of rubber-tired skidding using a grapple. The average production equation is T = 2.0 + 0.01(D), again where T is turn time in minutes and D is one-way skidding distance in feet. The assumptions used in developing the table were:

- Machine utilization would be 80 percent.
- Machine cost would be $25 per hour and the operator cost $15 per hour.
- The skidder would turn prebunched material. Fifteen pieces per load was assumed for pieces up to 5 ft^3 and 10 pieces per load was assumed for piece sizes greater than 5 ft^3. The maximum load size was 150 ft^3.

Hook and unhook time is greatly reduced when grapples are used and most of the cost is movement to and from the landing. If piece counts were reduced from 10 to 5, the costs of grapple skidding would approximately double. If (given the same size material) piece counts were reduced from 10 to 2, then skidding costs would increase by approximately fivefold. In fact, the inability of grapple skidders to get a sufficient number of pieces without bunching generally precludes their use when feller bunchers are not used.

Table 5 illustrates the costs of skidding with crawler tractors with chokers. The production equation was estimated to be T = 17.7 + 0.013 (D). The assumptions used in developing the tables were:

- Machine utilization would be 80 percent.
- Machine costs were developed for tractors in the 60-80 h.p. range and were estimated at $18 per hour. Operator costs were $15 per hour.
- The skidder turned 10 pieces, with a maximum load size of 150 ft^3.

Table 6: Cost of Cable Yarding. The costs of the large cable systems were developed from Withycombe (1982). The production estimates are derived from an array of highlead and skyline systems. The number of pieces yarded per shift (N) is estimated at N = (208 - 2V) for piece volumes of 0.5 to 50 ft^3 where V equals volume per piece. For pieces greater than 50 ft^3, the production equation is N = (133 - 0.5V). The estimated cost per day for the equipment and a four-man crew is $1,100. The cost for this system should be used for yarding distances under 1,000 feet. For distances from 1,000 to 2,000 feet, the table values should be increased 20 percent because of the increased yarding time. The table should not be used for distances over 2,000 feet.

The cost and production data for the small skyline systems were developed from thirteen studies: Aubuchon (1982), Cottell et al. (1976), Heidersdorf (1978), Hensel and Johnson (1979), Host (1983), Johnson and Lee (1982), Johnson (1982), Kellogg (1980, 1981), Mann and Miffling (1979), McMorland and Wong (1982), McMorland (1978), and Seabaugh and Yerkes (1979). The number of pieces yarded per shift based on productive machine hours was estimated at N = 351 - 5.6V, where N equals number of pieces yarded per 8-hour shift and V equals volume per piece. This equation assumes 3 pieces per turn for pieces up to 30 ft^3 and a yarding distance not exceeding 1,000 feet. For development of table 6, machine utilization was estimated at 80 percent. The machinery used to develop the estimate had skyline sizes less than 11/16 inches. The price range of the machinery was $48,000 to $100,000 in 1982. The average cost figures used to develop the table include $27 per hour for the yarder, $16 per hour for the yarder engineer, and $13.5 per hour for each of the two choker setters. When a skidder is used to shuttle the forest residue away from the yarder, an additional hourly cost of $35 is incurred.

Table 7: Cost of Loading and Hauling: Loading production data were derived from a variety of machines used in the northern Rocky Mountains. The principal sources of information were Lavoie (1980), Powell (1981), U.S.D.A. Forest Service (1983), and U.S.D.A. Forest Service, unpublished data (1983). Loading costs assume $22 per hour for the logging truck, $15 per hour each for the truck driver and loader operator, and a loader cost of $32 per hour.

The expected time to load a log truck varied by piece size. The following table shows the relationship between the average piece size and the

estimated time it takes to load a conventional logging truck, assuming 70 percent utilization of the loader.

Average piece size	Loading Time
60 ft^3 or above	20 minutes
40 ft^3 - 59 ft^3	30 minutes
20 ft^3 - 39 ft^3	40 minutes
10 ft^3 - 19 ft^3	50 minutes
9 ft^3 and below	60 minutes

On highway log trucks were assumed to have a maximum load of 52,000 pounds or 1,040 cubic feet[3]. For smaller pieces, the assumed load was reduced because of the difficulty of loading many small pieces on a truck. Withycombe estimated that for pieces smaller than 10 cubic feet, the load size would steadily be reduced to 34,000 pounds for pieces measuring 1 cubic foot (Withycombe 1982). The roundtrip time and hauling cost are dependent on both the total distance and type of roads. For construction of table 7, the round-trip time and road conditions were developed from Withycombe (1982). The table assumes dirt roads would comprise 10 percent of the total distance, with a minimum of 2 miles and maximum of 5 miles; gravel roads constitute 20 percent of the total, with a minimum of 2 miles and a maximum of 15 miles; and paved roads comprise the remainder. If significant departures from these assumptions occur, the costs per load should be modified by $1.80 for every mile of dirt road greater or less than the assumed value and by $1.00 for every mile of gravel road. The average cost for the log truck is $22 per hour plus $0.19/mile for fuel when hauling is averaged over all types of roads. The assumed cost of the truck driver is, again, $15 per hour.

<u>Table 8: In-Woods Chipping and Hauling</u>. Portable chippers are available in various sizes and able to handle most residue encountered in the northern Rocky Mountains. Many case studies in a variety of conditions have been conducted. The cost and production data used to develop table 8 came from the following: Goetz (1982), Host and Lowery (1983), Johnson (1983) unpublished data, Mandzak et al. (1981), Powell (1982), and Withycombe (1982). Production varied greatly depending on chipper size and continuity in supply of residue. For example, production ranged from a low of 4 cunits per production machine hour (PMH) for the smaller chippers that cost about $45 per hour (including labor) to a high of 19 cunits per PMH for the larger machines costing approximately $75 per hour.

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[3]The maximum load was recently increased to 53,000 pounds or roughly 10.6 cunits. The cost tables do not reflect this change; however, the effect on cost is minimal. In addition the weight of the load is based on green timber with 50 percent moisture content. Some components of forest residue such as standing dead timber may have a considerably lower weight per cunit. Truck loads would contain more material and the cost of hauling dead material based on this model would be overestimated.

From the case studies examined it was apparent that inefficient machine utilization is a common problem associated with in-woods chipping. This generally results from an insufficient volume of material delivered to the chipper. For the cost estimates developed in table 8, machine utilization of 70 percent was assumed. The average cost of producing unbarked chips was $8.6 per cunit and $10.4 per cunit for barked chips.

The chips are assumed to be hauled in 10-cunit capacity vans. The costs in table 8 include a truck and two standard highway vans. One van will be left at the site to be filled while the other is being hauled to the mill. Hourly cost is estimated at $25 for the chip truck and two chip vans. A variable cost of $0.19/mile is assigned while hauling. Roundtrip times were assumed to be the same as for log trucks.

Again, large variations from the costs in table 8 will occur if the requirements for effective chipping (a continuous supply of material to the chipper, effective utilization of the chipper's capacity, and adequate landing to allow free movement of material and the chip vans) are not met.

Table 9: Cost of In-Plant Chipping. The costs of in-plant chipping in table 9 are taken directly from Withycombe (1982). The cost figures have been updated to 1982 dollars by the implicit price deflator for personal consumption expenditures. The figures include the cost of a stationary chipper, with the necessary labor and power to produce chips for fuel. If chips are to be used for paper, an additional cost of $8.6 is incurred for barking, bark and chip handling and storage, and screening of the finished chips.

Table 10: Loading Cost and Table 11: Hauling Cost. Tables 10 and 11 illustrate the loading and hauling costs, respectively, that were combined in table 7. These are provided for those circumstances where adjustments to either the loading or the hauling costs are needed to account for local conditions. The section describing table 7 provides the assumptions used in constructing tables 10 and 11.

Table 12: Volumes of Selected Stems and Stem Segments in Typical Northern Rocky Mountain Stands. The cubic foot volumes shown in table 12 were used in converting the data from the various sources to a common measurement of cubic feet. The column headed "Total Volume (including top)" was derived from gross volume tables developed by Faurot (1977) by averaging the volumes for typical tree heights for the four common Rocky Mountain species: ponderosa pine, lodgepole pine, western larch, and Douglas-fir. To obtain volumes without bark, reduce the values in table 12 by 8 percent for lodgepole pine and by 20 percent for the others. The column headed "Total Volume (including top and crown)" was derived from slash weight tables developed by Brown et al. (1977) in addition to the bole volumes developed by Faurot.

Estimating the Cost of Whole Tree Recovery Systems

A whole tree recovery system theoretically offers the least expensive source of forest residue -- the tops and crowns of sawtimber trees. Currently there is little information on the feasibility of recovering top and crown volume by hauling whole trees in the northern Rocky Mountains. Some sawmills have hauled whole trees in the region under the assumption that limbing and bucking at the mill yard was cheaper than in-woods. But these attempts usually involved only small diameter lodgepole pine. No data on wood fiber recovery or cost are available.

Information on recovery is available from other regions in Hedin (1980), Lavoie (1980), and Routhier (1982). These studies indicate that whole tree hauling can result in the recovery of large volumes of additional wood fiber fairly inexpensively. Felling, limbing, bucking, and skidding costs frequently were unaffected or reduced when a whole tree operation was substituted for a conventional log-length operation. That is, a whole tree could be moved from the stump to the landing on the logging site for a similar, or perhaps reduced, cost than would be incurred to move only the logs in that tree. Felling, limbing, bucking, and skidding costs constitute a significant portion of harvest costs and preventing this charge to limb and top wood should create substantial cost savings.

Unfortunately, recovery rates and costs vary greatly. The recovery of top and crown wood requires expensive equipment and involves high fixed costs. Necessary equipment would include a whole tree processor (i.e. Hahn-Harvester) and a chipper, both expensive and required to run close to capacity to guarantee low cost. However, given sufficient volumes of top and crown wood, chipping, limbing, and topping costs involving a whole tree processor should be low. In fact, limbing costs for small diameter sawtimber using the Hahn-Harvester at high capacity should be lower than by hand, resulting in cost savings.

If the volume of top and crown wood recovered is low, the utilization level of the equipment drops and the cost per cunit of operating the machines is high, making recovery of top and crown wood expensive.

Volume recovered varies according to species, size of the timber, season of the year, and logging method. Because the volume of top and crown wood recoverable fluctuates greatly, the authors feel the tables presented in this model should only be used to estimate a range of costs for recovering top and crown wood.

Moving the tops and crowns from the landing to the mill site involves one of two methods. One is to haul whole trees to the mill and limb, top and chip at the mill. The second involves processing in the woods and hauling sawlogs and chipped tops and crowns separately.

The major costs in either case are for hauling and chipping. If a whole tree hauling approach is used, loading costs must be considered.

Whole Trees Processed on the Logging Site. Chipping and haul costs are incurred to recover wood fiber from the tops and crowns of sawtimber trees processed on the logging site. Table 8 should provide reasonable estimates of in-woods chipping costs and haul costs assuming high machine utilization levels. Given the numerous factors which could limit the ability of a whole tree system to maintain high equipment operating levels, the authors suggest that cost estimates be made for a range of equipment utilization levels. The costs in table 8 should be used to estimate minimum cost per cunit of chipping and hauling tops and crowns in the woods. Chipping costs of \$8.6 per cunit for chips not barked could easily triple if there is insufficient material to feed the chipper. A chipping cost of three times this rate, \$25.8 per cunit, would make a reasonable upper bound for an in-woods system. The suggestion is to increase the cost of not barked chips in table 8 by \$17.2 per cunit to provide an upper bound for the cost range.

Again, a user must keep in mind that if sufficient volumes of material are not available to operate the equipment near capacity, the limbing and bucking costs avoided will not offset the cost of operating the whole tree processor. The costs of top and crown wood would then be very high.

Whole Trees Processed at a Mill Site. If the material is hauled as whole trees to a mill site, relevant costs of recovering tops and limbs should include loading and haul costs as well as in-plant chipping costs. Obviously, an additional haul cost would be incurred when the top and crown wood is to be utilized at a site other than the mill processing the sawtimber.[1] The assumption is that utilization of chipping equipment (and whole tree processors) would increase greatly at the mill site. The chipping costs of \$8.6 per cunit from table 8 should, therefore, provide a good estimate of chipping costs. Haul costs per cunit should be the same as for logs using the cost per cunit column in table 11.

Loading costs could be much higher than those shown in table 10. The source for increased loading and unloading costs is a single study which indicated a 30 percent increase in loading and unloading time when whole trees were loaded rather than logs (Lavoie 1980). A study by Routhier (1982) also indicated increased costs of loading and unloading whole trees, but did not provide detailed time and cost estimates. The total load weight per truck in both studies was the same.

This 30 percent increase resulted in the recovery of only 17 percent more wood fiber per tree in the form of top and crown wood. This means top and crown wood would be nearly three times more expensive to load

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[1] A related whole tree approach is one in which whole trees are hauled to a centralized yard and processed. The logs would then have to be reloaded for haul to the mills. This would involve additional log handling costs. If the whole trees are processed at a centralized yard and then reloaded for haul to the mill site, these costs should range from \$15 to \$25 per thousand board feet. This would increase the cost of top and limb wood recovered by an estimated \$25 to \$100 per cunit.

than the logs. Because the study dealt with small diameter balsam fir and black spruce, it may not accurately reflect the situation in the northern Rocky Mountains. It does indicate, however, that loading costs for tops and limbs attached to whole trees can be considerably higher than for logs.

The authors suggest that a cost range be established for loading costs and recommend that when using table 10 to estimate the relevant costs of loading tops and crowns attached to whole trees 1) the average piece size be determined by the volumes of the bole; 2) the cost shown in table 10 be established as a lower bound; and 3) a cost of three times that in table 10 be used as an upper bound.

APPENDIX C

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